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(73)特許権者　000010098
アルプス電気株式会社
東京都大田区雪谷大塚町１番７号
(72)発明者　平井　敏雄
宮城県仙台市泉区高森３－４－91
(72)発明者　増本　博
宮城県仙台市青葉区上杉３－８－22
(72)発明者　王　新栄
宮城県多賀城市丸山一丁目２－５－11
(72)発明者　染野　義博
東京都大田区雪谷大塚町１番７号　アルプス電気株式会社内

審査官　峰　祐治

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(54)【発明の名称】　光学多層膜フィルタ

(57)【特許請求の範囲】

【請求項１】　単一方向に誘電体薄膜を多層に積層した光学多層膜フィルタであって、高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層とを交互に積層した交互積層部を中央に配し、該交互積層部に近い側が屈折率が高く該交互積層部から離れるに従って屈折率が段階状に順次傾斜減少する屈折率傾斜積層部を、前記交互積層部の両側に各々配し、前記交互積層部と前記屈折率傾斜積層部との間には、それぞれ屈折率差調整部が配され、

前記屈折率差調整部は、前記屈折率傾斜積層部における前記交互積層部に最も近い層の屈折率と前記交互積層部を構成する低屈折率層の屈折率との間の屈折率であり前記交互積層部に近づくにつれ段階状に減少してゆく層と、

前記屈折率傾斜積層部における前記交互積層部に最も近い層の屈折率と前記交互積層部を構成する高屈折率層の屈折率との間の屈折率であり前記交互積層部に近づくにつれ段階状に増大してゆく層とを交互に積層してなることとを特徴とする光学多層膜フィルタ。

【請求項２】　前記屈折率差調整部は、$SiO_2$と$TiO_2$との組成比を異ならせることにより所望の屈折率に形成されてなることを特徴とする請求項１記載の光学多層膜フィルタ。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、例えば波長分割多重光通信などにおいて、所望の波長の光を分波する光分波フィルタに係り、特に屈折率の異なる誘電体薄膜を多層に積層した光学多層膜フィルタに関する。

【０００２】

【従来の技術】波長分割多重通信(WDX: wavelength division multiplexing)は光通信容量の飛躍的な増大に対応する新たな技術として、近年、その開発が進んでいるが、波長多重数の更なる増大が望まれている。このような光通信においては、所望の波長の光を選択的に用いるために、異なる2から3種の誘電体薄膜を交互に積層した誘電体多層膜からなる光分波フィルタが用いられている。このような光学多層膜フィルタについて以下に説明する。図６は従来の光学多層膜の構造を示す説明図である。膜に吸収がない場合、屈折率(n0) の基板上のp+1層の多層膜から入射した光の反射率(R)と振幅反射率rp+1,0は、以下の関係を有する。

【０００３】

【数１】

$$R_{P+1,0}=\left|r_{P+1,0}\right|^2$$

rp+1,0 が振幅反射率で、

【０００４】

【数２】

$$r_{P+1,0}=\frac{\rho_{P+1,P}+r_{P,0}\exp(-i\delta_P)}{1+\rho_{P+1,P}r_{P,0}\exp(-i\delta_P)}$$

＊

＊を満たす。式中のdpとrp+1,p はそれぞれ位相，p+1層とp 層間の振幅反射率であり、以下の関係がある。

【０００５】

【数３】

$$\delta_P=\frac{4\pi}{\lambda}n_P d_P\cos\phi_P$$

l は 入射光の波長で、 np、dp はそれぞれp 層薄膜の屈折率および膜厚である。fpは光のp層内における屈折角である。フレネル(Fresnel)の法則により

【０００６】

【数４】

$$\rho_{P+1,P}=\frac{u_P-u_{P+1}}{u_P+u_{P+1}}$$

ただし、s偏光の場合、 p偏光の場合にはそれぞれ

【０００７】

【数５】

$$u_i=n_i\cos\phi_i \qquad (i=0,1,2....)$$

【数６】

$$u_i=\frac{n_i}{\cos\phi_i} \qquad (i=0,1,2....)$$

である。任意の光学特性に対する光学多層膜の積層構造の最適化には、従来から図式解法や解析合成法が用いられて来た。しかし、最近はパーソナルコンピュータを用いた自動計算が一般化している。

【０００８】次に、図７（ａ）、（ｂ）、図３をもとに、このような従来の光学多層膜フィルタについて更に説明する。図７（ａ）は高低屈折率の誘電体薄膜を交互に積層した光学多層膜フィルタにおける積層数と屈折率の関係を示す図であり、図７（ｂ）は図７（ａ）に示す光学多層膜フィルタにおける透過特性の計算結果を示す図であり、図３は膜の材質および屈折率を示す図である。このような従来の光学多層膜フィルタとして図７（ａ）に示すものにおいては、高屈折率の誘電体薄膜Hと、低屈折率の誘電体薄膜Lを交互に積層して形成している。ここで、 H、Lはそれぞれ図３に示した光学特性を有する$TiO_2$、$SiO_2$膜である。透過スペクトルの計算において、光の入射角を0（垂直入射）とし、中心波長を730 nm とした。このような従来の光学多層膜フィルタにおいては、中心波長（730nm）の反射バンドでほぼ100%の反射率を有するが、透過帯域で多くの干渉ピークが存在するという問題があり、高精度な光学フィルタを得ることは困難であった。

【０００９】一方、前述した従来の光学多層膜フィルタにおける光学特性を改善するものとして、誘電体薄膜の膜厚方向に対する屈折率を正弦などの関数に従って連続かつ周期的に変化させた構造としたルゲート型フィルタが知られている。この第２の従来例としてのルゲート型フィルタについて、図８（ａ）、（ｂ）をもとに説明する。図８（ａ）はルゲート型フィルタの積層数と屈折率の関係を示す図であり、図８（ｂ）は図８（ａ）に示すルゲート型フィルタにおける透過スペクトルの計算結果を示す図である。前述した高低屈折率薄膜を交互積層した光学多層膜フィルタの構成と比較するために、図８（ａ）には、正弦関数の一周期に対応する膜厚を交互多層膜の2層と見なして、屈折率と膜の積層数の関係を示した。ルゲート型フィルタの屈折率(n)の膜厚(x)依存性

は以下の式で表わせる。

【0010】

【数7】

$$n(X) = n_0 + n_1 \sin(2\pi X / P)$$

【0011】ここで、n0、n1はそれぞれ平均屈折率と屈折率変化の振幅であり、pは一つの正弦周期の膜厚である。図8（a）に示したように、ルゲート型フィルタは膜厚方向に対して屈折率が正弦関数に従って連続かつ周期的に変化する構造を有している。そして、図8（b）から明らかなように、ルゲート型フィルタは高低屈折率層を交互積層した光学多層膜フィルタより、透過領域での干渉を抑制し、低波長範囲の調和反射ピークも減少するが、反射バンド近傍の反射ピークは削除できない。そこで、ルゲート型フィルタにおいては、反射バンド近傍における干渉ピークを解決するため、フィルタ設計にあたってその光学特性を調整する他の関数が必要となる。たとえば、ルゲート型フィルタの構造に5次方関数及びFourier関数などを加えることによって、広帯域反射型フィルタの光学特性を改善することが可能となる。しかしながら、フィルタ構成が極めて複雑になるため、作製はより困難なものとなる。

【0012】

【発明が解決しようとする課題】このように、高屈折率の膜と低屈折率の膜を交互積層した従来の光学多層膜フィルタにおいては、狭いバンド幅や、温度変化に対する安定性などの要求性能を満たすことが困難であるという問題があった。また、ルゲート型フィルタにおいては、フィルタ構成が複雑であり、また、設計値に従って屈折率を連続的にかつ高精度に成膜するための制御が困難であり、生産性が低く、安定した品質で安価に提供することが困難であるという問題があった。本発明の課題は上記の従来例の問題を解決し、干渉が少なく光学特性の良い光学多層膜フィルタを提供することにある。また、生産性の高い光学多層膜フィルタを提供することにある。

【0013】

【課題を解決するための手段】前記課題を解決するための手段として、本発明の光学多層膜フィルタは、単一方向に誘電体薄膜を多層に積層した光学多層膜フィルタであって、高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層とを交互に積層した交互積層部を中央に配し、この交互積層部に近い側が屈折率が高く交互積層部から離れるに従って屈折率が段階状に順次傾斜減少する屈折率傾斜積層部を、交互積層部の両側に各々配し、交互積層部と屈折率傾斜積層部との間には、それぞれ屈折率差調整部が配されるものであり、ここで、屈折率差調整部が、屈折率傾斜積層部における交互積層部に最も近い層の屈折率と交互積層部を構成する低屈折率層の屈折率との間の屈折率であり交互積層部に近づくにつれ段階状に減少してゆく層と、屈折率傾斜積層部における交互積層部に最も近い層の屈折率と交互積層部を構成する高屈折率層の屈折率との間の屈折率であり交互積層部に近づくにつれ段階状に増大してゆく層とを交互に積層してなることを特徴とするものである。かかる構成により、本発明によれば、干渉が少なくて光学特性が良く、しかも生産性に優れた光学多層膜フィルタが提供可能となる。

【0014】また、上記構成に加えて、屈折率差調整部が$SiO_2$と$TiO_2$との組成比を異ならせることにより所望の屈折率に形成されてなるものであると良い。これにより、屈折率差調整部を容易に所望の屈折率に調整可能となる。

【0015】

【0016】

【0017】

【0018】

【0019】

【0020】

【発明の実施の形態】制御光波長に対して十分に薄い膜を積層した場合、制御光はこれを積層膜とは認識せず積層構造に応じる等価的な単一屈折率膜として感応する。この性質を利用して2種類の異なる屈折率膜の積層構造を変化させることで、膜厚方向に対して連続的に変化した特性を有する光分波フィルタを得ることが可能である。また、単一膜において2種類の異なる素材の組成比率を制御することで、任意の屈折率を有する膜を得るにはヘリコンスパッタ法等、膜の制御性の高い成膜法を用いることにより、所望の屈折率を有する単一光学膜の安定成膜が可能になる。本発明に係わる光学多層膜フィルタは、上述の点に着目し、高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層とを交互に積層した交互積層部を中央に配し、交互積層部に近い側が屈折率が高く交互積層部から離れるに従って屈折率が段階状に順次傾斜減少する屈折率傾斜積層部を、交互積層部の両側に各々配しており、しかも交互積層部と屈折率傾斜積層部との間にはそれぞれ屈折率差調整部が配される。そして、各屈折率差調整部は、屈折率傾斜積層部における交互積層部に最も近い層の屈折率と交互積層部を構成する低屈折率層の屈折率との間の屈折率であり交互積層部に近づくにつれ段階状に減少してゆく層と、屈折率傾斜積層部における交互積層部に最も近い層の屈折率と交互積層部を構成する高屈折率層の屈折率との間の屈折率であり交互積層部に近づくにつれ段階状に増大してゆく層とを交互に積層してなる構成としている。このように構成した光学多層膜フィルタによれば、成膜における再現性と制御性を確保しつつ、光学特性設計のより高い自由度を確保することが出来る。そして、干渉が少なく光学特性のよい、また、生産性の高い光学多層膜フィルタを提供することが可能となる。

【0021】

【実施例】本発明の実施例について図面を参照して以下

に説明する。図１（ａ）は本発明の一実施例に係わる光学多層膜フィルタの屈折率と膜厚の関係を示す図であり、図１（ｂ）はその断面構造の概念を示す説明図である。本発明の光学多層膜フィルタは、単一方向に誘電体薄膜を多層に積層した光学多層膜フィルタであって、図１（ａ）に示すように、高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層とを交互に積層した交互積層部Ａを中央に配し、交互積層部Ａに近い側が屈折率が高く交互積層部Ａから離れるに従って屈折率が段階状に順次傾斜減少する屈折率傾斜積層部Ｃを、交互積層部Ａの両側に各々配しており、しかも交互積層部Ａと屈折率傾斜積層部Ｃとの間にはそれぞれ屈折率差調整部Ｂが配されている。ここで、各屈折率差調整部Ｂは、図１（ｂ）に示すように、屈折率傾斜積層部Ｃにおける交互積層部Ａに最も近い層の屈折率と交互積層部Ａを構成する低屈折率層の屈折率との間の屈折率であり交互積層部Ａに近づくにつれ段階状に減少してゆく層と、屈折率傾斜積層部Ｃにおける交互積層部Ａに最も近い層の屈折率と交互積層部Ａを構成する高屈折率層の屈折率との間の屈折率であり交互積層部Ａに近づくにつれ段階状に増大してゆく層とを交互に積層してなる。

【００２２】次に、本発明の一実施例としての広帯域反射フィルタを図２（ａ）、図２（ｂ）、図３、図４を参照して説明する。図２（ａ）は本発明の実施例に係わる広帯域反射フィルタとしての積層数と屈折率の関係を示す図であり、図２（ｂ）の実線は図２（ａ）に示す広帯域反射フィルタにおける透過スペクトルの計算結果を示している。図３は膜の材質および屈折率を示す図である。図４は本発明の実施例に係わる広帯域反射フィルタの透過スペクトル計算曲線と実験値を示す図である。本発明の一実施例としての広帯域反射フィルタは、$SiO_2$、$TiO_2$を素材として設計した31層の広帯域反射フィルタからなる。更に具体的には、各誘電体薄膜層を以下のように積層構成した。ＬＡＢＣＤＥＣＦＢＧＡＨ$(LH)^4$ＬＧＡＦＢＥＤＣＢＡＬここで、Ｌ、Ｈ、Ａ、Ｂ、Ｃ、Ｄ、Ｅ、Ｆ、Ｇは図３に示した光学膜厚($nd=\lambda/4$)を有する$SiO_2$-$TiO_2$複合膜である。そして、ＬＡＢＣＤＥとＥＤＣＢＡＬは対称的に屈折率が傾斜した$SiO_2$-$TiO_2$複合膜の積層である。（図１の説明図における屈折率傾斜層部Ｃに相当する。）また、ＣＦＢＧＡとＬＧＡＦＢの部分は$SiO_2$-$TiO_2$複合膜からなる屈折率差調整部である。（図１の説明図における屈折率差調整部Ｂに相当する。）このように、上記屈折率差調整部を異なる複数の（好ましくは４種類以上）単一屈折率膜によって形成している。更に、上記の屈折率傾斜積層部と屈折率差調整部は、$SiO_2$と$TiO_2$の組成比を図３に示すように各々異ならせて所望の屈折率に形成した単一屈折率膜を用いて構成している。また、中心部分のＨ$(LH)^4$は従来の$TiO_2$、$SiO_2$単層膜からなる高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層の交互積層である。（図1の説明図における交互積層部Ａに相当する。）また、設計膜厚は3119 nmである。このようにして設計した本発明の一実施例に係わる広帯域反射フィルタについて、ヘリコンスパッタ法を用いて作製し、実験した。ヘリコンスパッタ法は、マグネトロンカソード上に誘導放電用コイルを設け、ヘリコン波を発生させることにより励起されたプラズマを用いてスパッタリングを行う方法である。このため、低プラズマダメージ、高密度の多成分膜の精密成膜が可能となる。ヘリコンスパッタ装置には二台のヘリコンカソードが用いられている。ヘリコンカソードにはそれぞれ溶融シリカ(99.99%)と焼結酸化チタン(99.5%)のターゲットが取りつけられている。ターゲットおよび誘導コイルにはrf (13.56 MHz) 電力を印加し、電力は0〜200Wとした。成膜時のチャンバーの基礎圧力は $5\times10^{-5}$Pa 以下とした。カソードとラジカルガンに導入したアルゴンと酸素ガスの比は$Ar/O_2=2/1$とし、成膜圧力は$1.8\times10^{-1}$Paとした。基板とターゲット間距離は180mmとし、基板は10rpmで回転させた。基板には光学ガラス (BK7, n=1.52)およびSi(100)単結晶基板を用いた。膜厚および屈折率はエリプソメーター(Gaertner L116-B,633nm)を用いて測定した。膜の組織観察はTEM (JEOL-200FX) で行った。多層膜の透過率は分光光度計 (Shimadzu UV-3101-200FX) を用いて200〜2500nmの波長範囲で測定した。これらによって作成した本発明の実施例に係わる光学多層膜について、その断面構造を観察すると図１に示すものと一致した。また図示しないが、TEM写真には、各層屈折率の増大つまり各層中の$TiO_2$含有量の増加に従って明視野像における明度が減少する傾向が見られる。なお、$SiO_2$、$TiO_2$および$SiO_2$-$TiO_2$複合膜のXRD、SEMおよびTEM解析により、$SiO_2$-$TiO_2$複合膜の微細構造は均質かつ等方的なアモルファス膜及びナノ結晶$TiO_2$を含むアモルファス膜であり、偏向依存性等がなく、光学的に均質な光学多層膜フィルタとして理想的膜構造としている。また、光学特性の評価結果、得られた多層膜の透過スペクトルは中心波長730nmで99.8%の反射率を有し、計算曲線とほぼ一致した。また、FWHM(full widthathalf maximum)においてもほぼ設計値と一致した。また、図２（ｂ）には、上述の本発明の実施例に係わる広帯域反射フィルタの計算透過スペクトルを実線で示しており、比較のために従来例に示した31層$TiO_2$、$SiO_2$交互積層による多層膜フィルタの計算透過スペクトルを破線で示している。図２（ｂ）より、本発明の実施例に係わる広帯域反射フィルタは、従来例の光学多層膜フィルタに比し、透過帯域での干渉が少なく、広帯域反射フィルタとしてより優れた光学特性が得られることがわかる。また、他の従来例として図８（ｂ）に示したルゲート型フィルタの透過スペクトルと比較すると、ルゲート型フィルタよりもさらに透過帯域での干渉が抑制されるということがわかる。このように本発明の

実施例に係わる広帯域反射フィルタにおいては、干渉を抑制し高い光学特性を得ることが可能となる。また、ルゲート型フィルタに比べ、簡単な膜構成とするこができるので、成膜における再現性と制御性を確保することができ、生産性の高い光学多層膜フィルタを提供することが可能となる。

【００２３】次に、本発明の他の実施例としての狭帯域透過フィルタを図５を参照して説明する。図５は本発明の実施例に係わる狭帯域透過フィルタの透過スペクトルの計算結果を示す図である。本発明の他の実施例としての狭帯域透過フィルタにおいても、本発明の第１の実施例と同様に、誘電体薄膜層の屈折率が膜の積層方向に対して順次傾斜変化する屈折率傾斜積層部Ｃと、高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層とを交互に積層した交互積層部Ａとを有し、屈折率差調整部Ｂが、交互積層部Ａと屈折率傾斜部Ｃ間に配されている。そして、基板からの積層方向に対して屈折率傾斜積層部Ｃ、屈折率差調整部Ｂ、交互積層部Ａ、屈折率差調整部Ｂ、屈折率傾斜積層部Ｃの順に成膜した構成となっている。具体的には、各誘電体薄膜層を以下のように積層構成している。

$$LABCDECFBGAxH(LH)^{n}LyH(LH)^{n}xHLGAFBEDCBAL$$

ここで、図５中の曲線$T_{124}$、$T_{663}$、$T_{282}$はそれぞれｘ＝１，ｙ＝２，ｎ＝４、ｘ＝６，ｙ＝６，ｎ＝３、ｘ＝２，ｙ＝８，ｎ＝２のパラメーターに対応し、各膜は図３に示す材料および屈折率からなる。そして、図５から明らかなように、本発明の実施例に係わる狭帯域透過フィルタにおいては、中心波長730ｎｍにおいてほぼ１００％の透過率が、また反射領域においてほぼ１００％の反射率が得られることがわかる。さらに、上述の多層膜のパラメータを調整することによって、透過バンド幅の波長範囲を1nmから50nmまで制御することが可能になり、狭帯域透過フィルタとしての高い光学特性を得ることが可能となる。＊

＊【００２４】

【発明の効果】以上説明したように、本発明によれば、誘電体薄膜層の屈折率が積層方向に対して順次傾斜変化する屈折率傾斜積層部と、高屈折率の誘電体薄膜層と低屈折率の誘電体薄膜層とを交互に積層した交互積層部とを備えるように積層したので、干渉が少なく光学特性の良い光学多層膜フィルタを提供することが可能になる。また、生産性の高い光学多層膜フィルタを提供することが可能となる。

【００２５】

【図面の簡単な説明】

【図１】本発明の実施例に係わる光学多層膜フィルタの屈折率と膜厚の関係、およびその断面構造の説明図である。

【図２】本発明の実施例に係わる広帯域反射フィルタとしての積層数と屈折率の関係、および透過スペクトルの計算結果を示す説明図である。

【図３】膜の材質および屈折率を示す図である。

【図４】本発明の実施例に係わる広帯域反射フィルタの透過スペクトル計算曲線、および実験値を示す説明図である。

【図５】本発明の実施例に係わる狭帯域透過フィルタの透過スペクトルの計算結果を示す説明図である。

【図６】従来の光学多層膜の構造を示す説明図である。

【図７】従来例に係わる交互積層多層膜フィルタにおける積層数と屈折率の関係、および透過特性の計算結果を示す説明図である。

【図８】従来例に係わるルゲート型フィルタの積層数と屈折率の関係、および透過スペクトルの計算結果を示す説明図である。

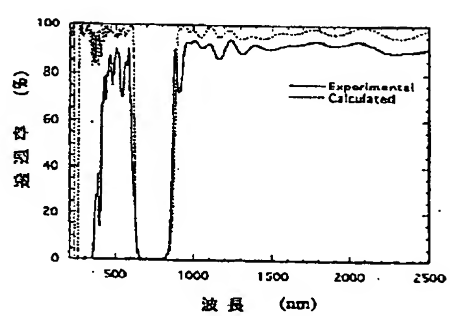
【符号の説明】

Ａ　交互積層部

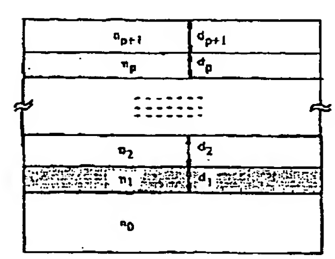
Ｂ　屈折率差調整部

Ｃ　屈折率傾斜積層部

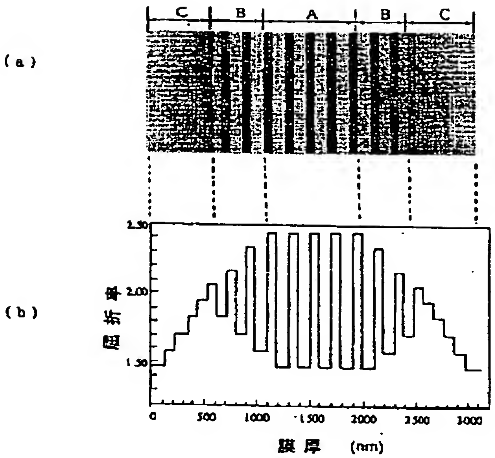
【図４】



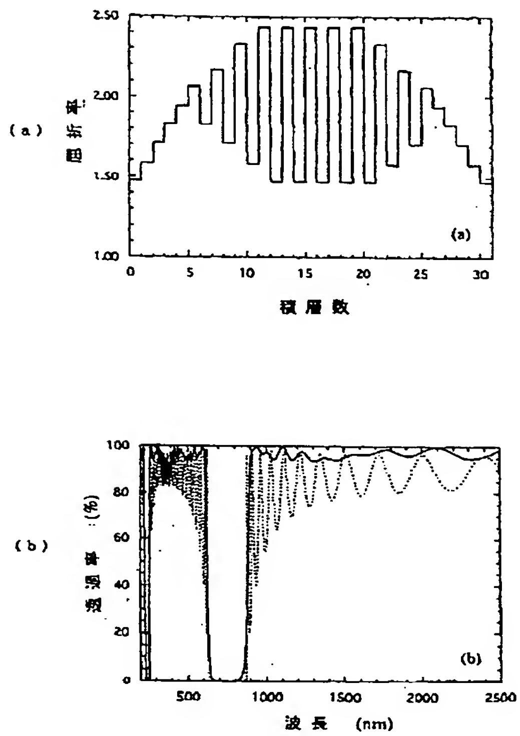

【図６】



【図１】



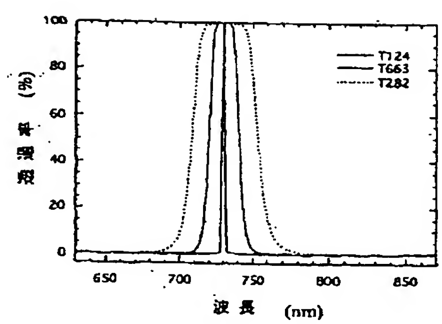

【図２】



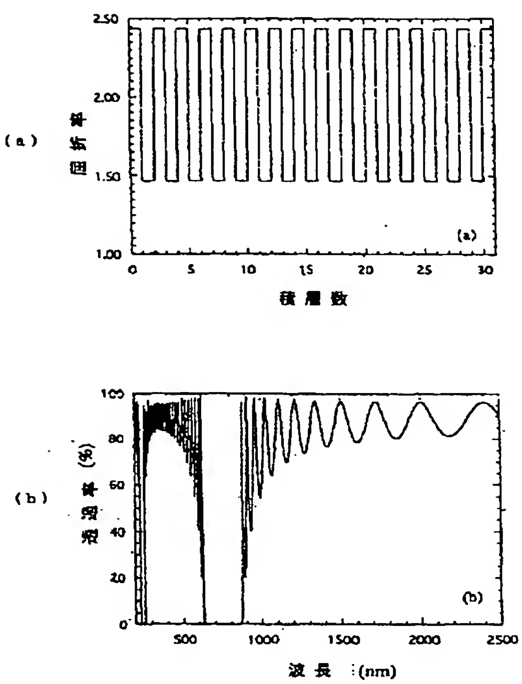

【図３】

| No | 構成 (mol:mol) | 屈折率 |
|---|---|---|
| H | $TiO_2$ | 2.435 |
| G | $0.87TiO_2$-$0.13SiO_2$ | 2.333 |
| F | $0.76TiO_2$-$0.24SiO_2$ | 2.170 |
| E | $0.65TiO_2$-$0.35SiO_2$ | 2.068 |
| D | $0.54TiO_2$-$0.46SiO_2$ | 1.942 |
| C | $0.45TiO_2$-$0.55SiO_2$ | 1.830 |
| B | $0.33TiO_2$-$0.67SiO_2$ | 1.714 |
| A | $0.17TiO_2$-$0.83SiO_2$ | 1.582 |
| L | $SiO_2$ | 1.471 |

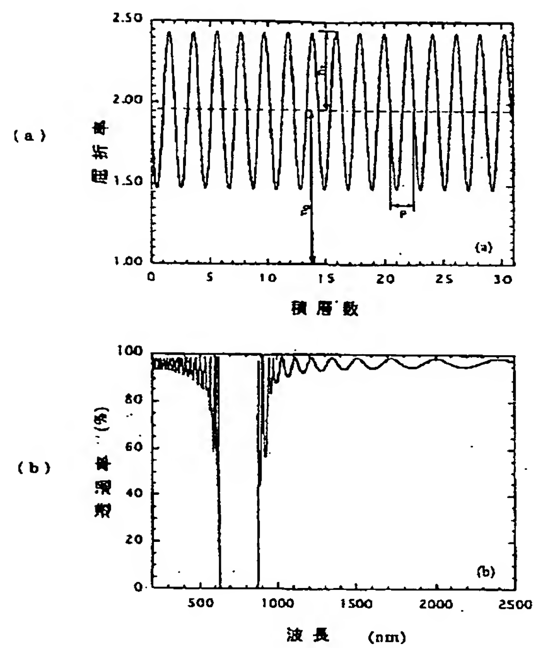
【図５】



【図7】




【図8】

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(58)調査した分野(Int.Cl.⁷，ＤＢ名)
G02B 5/28

# PATENT ABSTRACTS OF JAPAN

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(22)Date of filing : 22.06.1998
(71)Applicant : ALPS ELECTRIC CO LTD
(72)Inventor : HIRAI TOSHIO
MASUMOTO HIROSHI
O CHIKAE
SOMENO YOSHIHIRO

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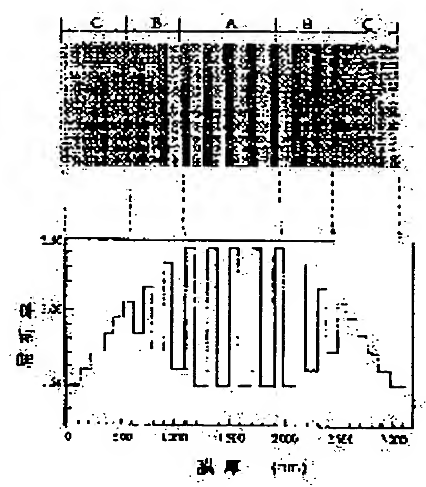
## (54) OPTICAL MULTILAYERED FILTER


(57)Abstract:
PROBLEM TO BE SOLVED: To provide optical multilayered filters having good optical characteristics without interference and the optical multilayered filters having high productivity.
SOLUTION: The optical multilayered filters formed by laminating dielectric thin films to multiple layers in a single direction are composed to have refractive index inclining lamination parts C where the refractive index of the dielectric thin film layers change successively incline and change in the lamination direction and alternate lamination parts A where the dielectric thin film layers of a high refractive index and the dielectric thin film layers of a low refractive index are alternately laminated. The color filters are composed by forming a plurality of the inclining lamination parts C and the alternate lamination parts A so as to hold these parts in the lamination direction.


(a)
(b)
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LEGAL STATUS

[Date of request for examination] 23.05.2000
[Date of sending the examiner's decision of rejection]
[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]
[Date of final disposal for application]
[Patent number] 3290629
[Date of registration] 22.03.2002
[Number of appeal against examiner's decision of rejection]
[Date of requesting appeal against examiner's decision of rejection]

[Date of extinction of right]

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CLAIMS

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[Claim(s)]
[Claim 1] An optical multilayers filter characterized by having the crosswise lamination section which carried out the laminating of the refractive-index inclination laminating section in which is the optical multilayers filter which carried out the laminating of the dielectric thin film to a multilayer in single direction, and a refractive index of a dielectric thin film layer carries out sequential inclination change to the direction of a laminating, and a dielectric thin film layer of a high refractive index and a dielectric thin film layer of a low refractive index by turns.
[Claim 2] An optical multilayers filter according to claim 1 characterized by forming more than one so that said inclination laminating section may be put in the direction of a laminating of said crosswise lamination section.
[Claim 3] An optical multilayers filter characterized by having the crosswise lamination section which carried out the laminating of the refractive-index inclination laminating section in which is the optical multilayers filter which carried out the laminating of the dielectric thin film to a multilayer in single direction, and a refractive index of a dielectric thin film layer carries out sequential inclination change to the direction of a laminating, and a dielectric thin film layer of a high refractive index and a dielectric thin film layer of a low refractive index by turns, and a refractive-index difference controller prepared among these laminating sections.
[Claim 4] Said refractive-index difference controller is an optical multilayers filter according to claim 3 characterized by consisting of two or more different single refractive-index films.
[Claim 5] An optical multilayers filter according to claim 3 characterized by preparing a refractive-index difference controller which comes to use a single refractive-index film formed in a desired refractive index by changing a presentation ratio of SiO2 and TiO2 between said refractive-index inclination laminating sections and crosswise lamination sections.
[Claim 6] The 1st refractive-index inclination laminating section which is the optical multilayers filter which carried out the laminating of the dielectric thin film to a multilayer in single direction, and carried out the laminating of the dielectric thin film to a multilayer so that a refractive index might carry out a sequential increment stair-like, An optical multilayers filter characterized by forming the crosswise lamination section which carried out the laminating of a dielectric thin film layer of a high refractive index, and the dielectric thin film layer of a low refractive index by turns, and the 2nd refractive-index inclination laminating section which carried out the laminating of the dielectric thin film to a multilayer so that a refractive index might carry out sequential reduction stair-like in above order.
[Claim 7] An optical multilayers filter according to claim 6 characterized by forming a refractive-index difference controller between said refractive-index inclination laminating sections and crosswise lamination sections.
[Claim 8] An optical multilayers filter according to claim 6 characterized by preparing a refractive-index difference controller which comes to use a single refractive-index film formed in a desired refractive index by changing a presentation ratio of SiO2 and TiO2 between said refractive-index inclination laminating sections and crosswise lamination sections.
[Claim 9] Said refractive-index inclination laminating section is the optical multilayers filter of any of claims 1, 3, and 6 characterized by forming using a single refractive-index film formed in a

desired refractive index, or one publication by changing a presentation ratio of $SiO_2$ and $TiO_2$.

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[Translation done.]

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## DETAILED DESCRIPTION

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[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] This invention relates to the optical multilayers filter which carried out the laminating of the dielectric thin film with which the optical spectral separation filter which separates the light of desired wavelength spectrally is started, especially refractive indexes differ to the multilayer for example, in wavelength division multiplex optical communication etc.
[0002]
[Description of the Prior Art] As new technology corresponding to the increase of optical-communication capacity with fast wavelength division multiplying (WDX: wavelength division multiplexing), although the development is progressing in recent years, the further increase of wavelength many load resultant pulse numbers is desired. In such optical communication, in order to use the light of desired wavelength alternatively, the optical spectral separation filter which consists of dielectric multilayers which carried out the laminating of two to different three sorts of dielectric thin films by turns is used. Such an optical multilayers filter is explained below. Drawing 6 is explanatory drawing showing the structure of the conventional optical multilayers. the case where there is no absorption in a film -- refractive index (n0) p+1 on a substrate the reflection factor (R) of the light which carried out incidence from the multilayers of a layer, and amplitude-reflectance rp+ -- 1 and 0 have the following relation.
[0003]
[Equation 1]

$$R_{P+1,0}=|r_{P+1,0}|^2$$

rp+ -- 1 and 0 [an amplitude reflectance -- 0004]
[Equation 2]

$$r_{P+1,0}=\frac{\rho_{P+1,P}+r_{P,0}\exp(-i\delta_P)}{1+\rho_{P+1,P}r_{P,0}\exp(-i\delta_P)}$$

********. dp in a formula, and rp+1 and p They are a phase, p+1 layer, and p, respectively. It is an amplitude reflectance between layers and there is the following relation.
[0005]
[Equation 3]

$$\delta_P=\frac{4\pi}{\lambda}n_P d_P\cos\phi_P$$

l ** At the wavelength of incident light, they are np and dp. It is p, respectively. It is the refractive index and thickness of a layer thin film. fp is the angle of refraction in p layers of light.

It is [0006] by Fresnel's (Fresnel) principle.
[Equation 4]

$$\rho_{P+1,P} = \frac{u_P - u_{P+1}}{u_P + u_{P+1}}$$

In however, the case of s-polarized light In the case of p-polarized light, it is [0007], respectively.
[Equation 5]

$$u_i = n_i \cos\phi_i \quad (i=0,\ 1,\ 2....)$$

[Equation 6]

$$u_i = \frac{n_i}{\cos\ \phi_i} \quad (i=0,\ 1,\ 2....)$$

It comes out. Graphical analysis and an analysis synthesis method have been used for optimization of the laminated structure of the optical multilayers to the optical property of arbitration from the former. However, the automatic ticketing which used the personal computer has become common recently.
[0008] Next, such a conventional optical multilayers filter is further explained based on drawing 7 (a), (b), and drawing 3 . Drawing 7 (a) is drawing showing the relation between the number of laminatings in the optical multilayers filter which carried out the laminating of the dielectric thin film of a height refractive index by turns, and a refractive index, drawing 7 (b) is drawing showing the count result of the transparency property in the optical multilayers filter shown in drawing 7 (a), and drawing 3 is drawing showing the membranous quality of the material and a membranous refractive index. In what is shown in drawing 7 (a) as such a conventional optical multilayers filter, the laminating of the dielectric thin film H of a high refractive index and the dielectric thin film L of a low refractive index is carried out by turns, and they are formed. Here, H and L are $TiO_2$ which has the optical property shown in drawing 3 , and $SiO_2$ film, respectively. The incident angle of light is set to 0 (vertical incidence) in count of a transparency spectrum, and it is 730 nm about main wavelength. It carried out. In such a conventional optical multilayers filter, although it had about 100% of reflection factor in the reflective band of main wavelength (730nm), it was difficult for there to be a problem that many interference peaks exist in a transparency band, and to obtain a highly precise light filter.
[0009] The RUGETO mold filter which made the refractive index to the direction of thickness of a dielectric thin film continuation and the structure where it was made to change periodically, according to functions, such as a sine, is known as what, on the other hand, improves the optical property in the conventional optical multilayers filter mentioned above. The RUGETO mold filter as this 2nd conventional example is explained based on drawing 8 (a) and (b). Drawing 8 (a) is drawing showing the relation of the number of laminatings and refractive index of a RUGETO mold filter, and drawing 8 (b) is drawing showing the count result of the transparency spectrum in the RUGETO mold filter shown in drawing 8 (a). In order to compare with the configuration of the optical multilayers filter which carried out crosswise lamination of the height refractive-index thin film mentioned above, it considered that the thickness corresponding to a round term of a sine function was two-layer [ of mutual multilayers ] to drawing 8 (a), and the relation between a refractive index and the membranous number of laminatings was shown in it. The thickness (x) dependency of the refractive index (n) of a RUGETO mold filter can be expressed with the following formulas.
[0010]
[Equation 7]

$$n(X) = n_0 + n_1 \sin(2\pi X / P)$$

[0011] Here, n0 and n1 are an average refractive index and the amplitude of refractive-index change, respectively, and P is the thickness of one sine period. As shown in drawing 8 (a), as for the RUGETO mold filter, the refractive index has continuation and the structure of changing periodically, according to the sine function to the direction of thickness. And although interference in a transparency field is controlled and the harmony reflective peak of a low wavelength range also decreases from the optical multilayers filter with which the RUGETO mold filter carried out crosswise lamination of the high refractive-index layer so that clearly from drawing 8 (b), the reflective peak near the reflective band cannot be deleted. Then, in a RUGETO mold filter, in order to solve an interference peak [ / near the reflective band ], other functions which adjust the optical property in a filter design are needed. For example, it becomes possible by adding a 5th way function, a Fourier function, etc. to the structure of a RUGETO mold filter to improve the optical property of a broadband reflective mold filter. However, since a filter configuration becomes very complicated, production will become more difficult.

[0012]

[Problem(s) to be Solved by the Invention] Thus, in the conventional optical multilayers filter which carried out crosswise lamination of the film of a high refractive index, and the film of a low refractive index, there was a problem that it was difficult to fill military requirements, such as a narrow bandwidth and stability over a temperature change. Moreover, in a RUGETO mold filter, control for a filter configuration to form membranes to high degree of accuracy continuously [ it is complicated and / refractive index ] according to a layout value was difficult, productivity was low, and there was a problem that it was difficult to provide cheaply in the stable quality. The technical problem of this invention solves the problem of the above-mentioned conventional example, and offering few good optical multilayers filters of an optical property has interference. Moreover, it is in offering an optical multilayers filter with high productivity.

[0013]

[Means for Solving the Problem] As said The means for solving a technical problem, an optical multilayers filter of this invention is an optical multilayers filter which carried out the laminating of the dielectric thin film to a multilayer in single direction, and was considered as a configuration equipped with the crosswise lamination section which carried out the laminating of the refractive-index inclination laminating section in which a refractive index of a dielectric thin film layer carries out sequential inclination change to the direction of a laminating, and a dielectric thin film layer of a high refractive index and a dielectric thin film layer of a low refractive index by turns.

[0014] Moreover, an optical multilayers filter of this invention was considered as a configuration formed so that said inclination laminating section might be put in the direction of a laminating of said crosswise lamination section as said The means for solving a technical problem. [ two or more ]

[0015] As said The means for solving a technical problem, moreover, an optical multilayers filter of this invention The refractive-index inclination laminating section in which is the optical multilayers filter which carried out the laminating of the dielectric thin film to a multilayer in single direction, and a refractive index of a dielectric thin film layer carries out sequential inclination change to the direction of a laminating, It considered as a configuration equipped with the crosswise lamination section which carried out the laminating of a dielectric thin film layer of a high refractive index, and the dielectric thin film layer of a low refractive index by turns, and a refractive-index difference controller prepared among these laminating sections.

[0016] Moreover, an optical multilayers filter of this invention was considered as a configuration which forms said refractive-index difference controller with two or more different single refractive-index films as said The means for solving a technical problem.

[0017] As said The means for solving a technical problem, moreover, an optical multilayers filter of this invention The 1st refractive-index inclination laminating section which is the optical multilayers filter which carried out the laminating of the dielectric thin film to a multilayer in single direction, and carried out the laminating of the dielectric thin film to a multilayer so that a refractive index might carry out a sequential increment stair-like, It considered as a

configuration which forms the crosswise lamination section which carried out the laminating of a dielectric thin film layer of a high refractive index, and the dielectric thin film layer of a low refractive index by turns, and the 2nd refractive-index inclination laminating section which carried out the laminating of the dielectric thin film to a multilayer so that a refractive index might carry out sequential reduction stair-like in above order.

[0018] Moreover, an optical multilayers filter of this invention is an optical multilayers filter according to claim 6 characterized by preparing a refractive-index difference controller which comes to use a single refractive-index film formed in a desired refractive index by changing a presentation ratio of SiO2 and TiO2 between said refractive-index inclination laminating sections and crosswise lamination sections as said The means for solving a technical problem.

[0019] Moreover, an optical multilayers filter of this invention was considered as a configuration formed using a single refractive-index film which formed said refractive-index inclination laminating section in a desired refractive index by changing a presentation ratio of SiO2 and TiO2 as said The means for solving a technical problem.

[0020]

[Embodiment of the Invention] When the laminating of the film thin enough is carried out to control light wave length, control light does not recognize this to be a cascade screen, but responds as an equivalent single refractive-index film according to a laminated structure. It is possible to obtain the optical spectral separation filter which has the property which changed continuously to the direction of thickness by changing the laminated structure of two kinds of different refractive-index films using this property. Moreover, the stable membrane formation of a single optical film which has a desired refractive index is attained by using high methods of forming a membranous controllability, such as the Helicon spatter method, for obtaining the film which has the refractive index of arbitration by controlling the presentation ratio of two kinds of different materials in simple gland. The optical multilayers filter concerning this invention is made into the structure equipped with the refractive-index inclination laminating section which carries out inclination change of the refractive index of a dielectric thin film to the direction of a laminating, and the height refractive-index crosswise lamination section paying attention to an above-mentioned point. Moreover, in addition to the above-mentioned configuration, the optical multilayers filter concerning this invention is considered as the configuration of the optical multilayers having a refractive-index difference controller with these laminating sections. Moreover, the optical multilayers filter concerning this invention forms the above-mentioned refractive-index difference controller with two or more different single refractive-index films. Furthermore, the optical multilayers filter concerning this invention is formed using the single refractive-index film which formed the above-mentioned refractive-index inclination laminating section or an above-mentioned refractive-index difference controller in the desired refractive index by changing the presentation ratio of SiO2 and TiO2. Thus, according to the constituted optical multilayers filter, the higher flexibility of optical property layout is securable, securing the repeatability and the controllability in membrane formation. And it is few and, in an optical property, interference becomes good possible [ offering an optical multilayers filter with high productivity ].

[0021]

[Example] The example of this invention is explained below with reference to a drawing. Drawing 1 (a) is drawing showing the refractive index of an optical multilayers filter and the relation of thickness concerning one example of this invention, and drawing 1 (b) is explanatory drawing showing the concept of the cross-section structure. The optical multilayers filter of this invention is constituted so that it may have the crosswise lamination section A which carried out the laminating of the refractive-index inclination laminating section C and the dielectric thin film layer of a high refractive index in which are the optical multilayers filter and the refractive index of a dielectric thin film layer carries out sequential inclination change to the membranous direction of a laminating, and the dielectric thin film layer of a low refractive index which carried out the laminating of the dielectric thin film to the multilayer in single direction by turns. Moreover, it has the controller B of the refractive-index difference of the above-mentioned A portion and C portion, and has composition which formed membranes to the direction of a

laminating from a substrate in order of the refractive-index inclination laminating section C, the refractive-index difference controller B, the crosswise lamination section A, the refractive-index difference controller B, and the refractive-index inclination laminating section C.

[0022] Next, the broadband reflective filter as one example of this invention is explained with reference to drawing 2 (a), drawing 2 (b), drawing 3 , and drawing 4 . Drawing 2 (a) is drawing showing the number of laminatings as a broadband reflective filter and the relation of a refractive index concerning the example of this invention, and the continuous line of drawing 2 (b) shows the count result of the transparency spectrum in the broadband reflective filter shown in drawing 2 (a). Drawing 3 is drawing showing the membranous quality of the material and a membranous refractive index. Drawing 4 is drawing showing the transparency spectrum count curve and experimental value of the broadband reflective filter concerning the example of this invention. The broadband reflective filter as one example of this invention consists of a broadband reflective filter of 31 layers which designed SiO2 and TiO2 as a material. Furthermore, specifically, the laminating configuration of each dielectric thin film layer was carried out as follows.

LABCDECFBGAH (LH) L, H, A, B, C, D, E, F, and G are SiO2-TiO2 bipolar membrane which has the optical thickness (nd=lambda/4) shown in drawing 3 4 LGAFBEDCBAL here. And LABCDE and EDCBAL are the laminatings of SiO2-TiO2 bipolar membrane where the refractive index inclined symmetrically. (It is equivalent to the refractive-index inclination laminating section C in explanatory drawing of drawing 1 .)

Moreover, the portions of CFBGA and LGAFB are height refractive-index crosswise lamination which consists of SiO2-TiO2 bipolar membrane. (It is equivalent to the refractive-index difference controller B in explanatory drawing of drawing 1 .) The above-mentioned refractive-index difference controller is formed in this way with two or more different single (preferably four or more kinds) refractive-index films. Furthermore, the above-mentioned refractive-index inclination laminating section and an above-mentioned refractive-index difference controller constitute the presentation ratio of SiO2 and TiO2 using the single refractive-index film which was changed respectively and formed in the desired refractive index, as shown in drawing 3 . Moreover, H(LH) 4 for a core are the crosswise lamination of the dielectric thin film layer of the high refractive index which consists of conventional TiO2 and SiO2 monolayer, and the dielectric thin film layer of a low refractive index. (It is equivalent to the crosswise lamination section A in explanatory drawing of drawing 1 .) Layout thickness is 3119 nm again. Thus, about the broadband reflective filter concerning one example of designed this invention, it produced and experimented using the Helicon spatter method. The Helicon spatter method is a method of performing sputtering using the plasma excited by preparing the coil for inductive discharge on a magnetron cathode, and generating a helicon wave. For this reason, precision membrane formation of a low plasma damage and the multicomponent film of high density is attained. Two sets of the Helicon cathodes are used for Helicon spatter equipment. The target of fused silica (99.99%) and sintering titanium oxide (99.5%) is attached in the Helicon cathode, respectively. In a target and an induction coil, it is rf (13.56 MHz). Power was impressed and power was set to 0-200W. Basic pressure of the chamber at the time of membrane formation 5x10 to 5 Pa It considered as the following. The ratio of a cathode, the argon introduced into the radical gun, and oxygen gas set to Ar/O2=2/1, and the membrane formation pressure was set to 1.8x10 to 1 Pa. A substrate and distance between targets were set to 180mm, and the substrate was rotated by 10rpm. In a substrate, it is optical glass. (BK7, n= 1.52) And Si (100) single crystal substrate was used. Thickness and a refractive index were measured using the ellipsomter (Gaertner L116-B, 633nm). Organization observation of a film is TEM (JEOL-200FX). It carried out. The permeability of multilayers is a spectrophotometer. (Shimadzu UV-3101-200FX) It used and measured in [ wavelength ] 200-2500nm. About the optical multilayers concerning the example of this invention created by these, when the cross-section structure was observed, it was in agreement with what is shown in drawing 1. Moreover, although not illustrated, the orientation for the lightness in a light field image to decrease according to increase of a class refractive index, i.e., the increment in TiO2 content in each class, is looked at by the TEM photograph. In addition, in XRD of SiO2, TiO2, and SiO2-TiO2 bipolar membrane, SEM, and TEM

analysis, the fine structure of SiO2-TiO2 bipolar membrane is an amorphous film including homogeneity, an isotropic amorphous film, and the nano crystal TiO2, does not have a deviation dependency etc. and is optically made into ideal membrane structure as a homogeneous optical multilayers filter. Moreover, the evaluation result of an optical property and the transparency spectrum of the obtained multilayers have 99.8% of reflection factor on the main wavelength of 730nm, and were mostly in agreement with the count curve. Moreover, also in FWHM (full widthat half maximum), it was mostly in agreement with the layout value. Moreover, the dashed line shows the count transparency spectrum of the multilayers filter according to TiO2 and SiO2 crosswise lamination 31 layers which shows the count transparency spectrum of the broadband reflective filter concerning the example of above-mentioned this invention as the continuous line, and was shown in the conventional example for the comparison to drawing 2 (b). The broadband reflective filter concerning the example of this invention is compared with the optical multilayers filter of the conventional example, there is little interference in a transparency band, and drawing 2 (b) shows that the optical property superior to as a broadband reflective filter is obtained. Moreover, it turns out that interference in a transparency band is further controlled rather than a RUGETO mold filter as compared with the transparency spectrum of the RUGETO mold filter shown in drawing 2 (b) as other conventional examples. Thus, in the broadband reflective filter concerning the example of this invention, it becomes possible to control interference and to obtain a high optical property. Moreover, since it can consider as an easy film configuration compared with a RUGETO mold filter, the repeatability and the controllability in membrane formation can be secured and it becomes possible to offer an optical multilayers filter with high productivity.

[0023] Next, the narrow-band transparency filter as other examples of this invention is explained with reference to drawing 5 . Drawing 5 is drawing showing the count result of the transparency spectrum of the narrow-band transparency filter concerning the example of this invention. Also in the narrow-band transparency filter as other examples of this invention, it constitutes so that it may have the crosswise lamination section which carried out the laminating of the refractive-index inclination laminating section in which the refractive index of a dielectric thin film layer carries out sequential inclination change to the membranous direction of a laminating, and the dielectric thin film layer of a high refractive index and the dielectric thin film layer of a low refractive index by turns. Furthermore, specifically, the laminating configuration of each dielectric thin film layer is carried out as follows.

LABCDECFBGAxH(LH) nLyH(LH) nxHLGAFBEDCBAL -- here, the curves T124, T663, and T282 in drawing 5 correspond to the parameter of x= 1, y= 2, n= 4, x= 6, y= 6, n= 3, x= 2, y= 8, and n= 2, respectively, and each film consists of the material and refractive index which are shown in drawing 3 . And in the narrow-band transparency filter concerning the example of this invention, it turns out that about 100% of reflection factor is obtained for about 100% of permeability in a reflective field again in the main wavelength of 730nm so that clearly from drawing 5 . Furthermore, by adjusting the parameter of above-mentioned multilayers, it becomes possible to control the wavelength range of a transparency bandwidth from 1nm to 50nm, and it becomes possible [ obtaining the high optical property as a narrow-band transparency filter ].

[0024]

[Effect of the Invention] Since the laminating was carried out according to this invention so that it might have the crosswise lamination section which carried out the laminating of the refractive-index inclination laminating section in which the refractive index of a dielectric thin film layer carries out sequential inclination change to the direction of a laminating, and the dielectric thin film layer of a high refractive index and the dielectric thin film layer of a low refractive index by turns as explained above, it enables interference to offer few good optical multilayers filters of an optical property. Moreover, it becomes possible to offer an optical multilayers filter with high productivity.

[0025]

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[Translation done.]